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METHOD FOR OPTIMIZING PLATES IN A PLATE-LINK CHAIN, AND PLATE FOR A PLATE-LINK CHAIN

The invention relates to a method for optimizing plates in a plate-link chain for use in a variable speed unit of a belt-driven conical-pulley transmission. The invention furthermore relates to a plate for such a plate-link chain.

Belt-driven conical-pulley transmissions with continuously variable transmission ratios are used increasingly in modern motor vehicles not only because of the driving comfort that can be achieved with them, but also for possible fuel consumption savings.

One component that is decisive for the durability and the torque transmission ability of the variable speed unit of such a belt-driven conical-pulley transmission is the endless torque-transmitting means itself, which can be designed for example as a plate-link chain, as illustrated diagrammatically in Fig. 5 in a small section. Such a plate-link chain is composed of plate-links 10, which are connected by means of rocker members 12 with each other. The plate-links 10 are arranged behind one another in several rows that are arranged adjacent to each other with respect to the direction of motion of the plate-link chain, wherein in Fig. 5 the plate 10_1 is part of the front row in the viewing direction, the plate 10_2 is part of a row adjacent to the front row, and plate 10_3 is part of another row. To connect the plates, rocker members 12 are provided, which penetrate the plate openings 14 transversely to the direction of motion, respectively. In doing so, two rocker member pairs 16_1 and 16_2 penetrate each plate opening, wherein the plates 12_1 and 12_2 are part of the rocker member pair 16_1 and the plates 12_3 and 12_4 are part of the rocker member pair 16_2. As can be seen, the

exterior sides of the rocker members 12_1 and 12_4, which face away from each other, of the rocker member pairs 16_1 or 16_2 are supported on the inside of the plate opening 14, either on the front or the rear inside in relation to the direction of motion of the plate-link chain. The rocker members 12_2 and 12_4 which face each other are supported on the insides of plate openings of plates arranged in adjacent rows. The surfaces of the rocker members of each rocker member pair facing each other form rolling surfaces, on which the rocker members roll against each other when the radius R at which the respective region of the plate-link chain is curved changes.

Such a plate-link chain as well as the corresponding variable speed unit with two conical disk pairs, around which the plate-link chain runs, are known as such and will therefore not be described in detail.

Fig. 6 shows a plate 10 and a rocker member 12 in an enlarged scale.

The rocker member 12 has two longitudinal legs 18 and two vertical legs 20, which jointly enclose the plate opening 14. According to Fig. 6, the rocker member 12, the rolling surface of which has been designated with the reference number 20, lies on the right side against the inside of the plate opening 14, wherein the contact surfaces have been adjusted with each other such that contact only occurs in the region of the transition between the longitudinal legs 18 to the vertical legs 20 and that in the region of the center of the vertical leg 20 no contact occurs. When the plate 10 according to Fig. 6 is moved from right to left, forces are transmitted on the contact surface accordingly through the force transmitted by the plate-link chain, as represented in the figures with the arrows F indicating the load centers of the force and the force directions. Due to the offset design of the application points of the force in relation to

the center of the longitudinal legs, tensile as well as bending stress act in the longitudinal legs 18. Likewise bending and tension stress act upon the vertical legs.

By nature, with given materials and given geometrical framework conditions of the respective variable speed unit, i.e. its division, minimal and maximum revolution radius of the plate-link chain etc. as well as the torque to be transmitted, the dimensions required for a plate depend on the stress that is active in the plate.

An object of the invention is to design plates such that with given framework conditions the plate is optimized with the goal of minimal material usage and hence minimal weight.

A first solution of that object is achieved with a method for optimizing the plates of a plate-link chain for use in a variable speed unit of a belt-driven conical-pulley transmission, with said plate-link chain comprising plates arranged behind one another in several rows arranged next to another transversely in relation to the direction of motion of the plate-link chain, wherein said plates overlap transversely in relation to the direction of motion and are connected by means of rocker members penetrating them transversely in relation to the direction of motion, wherein an opening of each plate is penetrated by two rocker member pairs, the rocker members of which face away from each other rest against the front or rear inside of the plate opening, and the rocker members facing each other rest against the front or rear inside of plate openings of adjacent plates; wherein the surfaces of the rocker members of each rocker member pair facing one another roll against each other when the plate-link chain bends, by which method the transmission of force from the rocker members into the plates occurs such that the bending stress of the longitudinal legs extending in the

direction of motion or the vertical legs extending perpendicular to the direction of motion of the plates resulting from the force transmission is minimized in given boundary conditions.

An advantageous embodiment of the method according to the invention consists of minimizing the bending moment MB of the longitudinal legs for the plate-link chain corresponding to the following formula in given boundary conditions:

$$MB = \frac{F * He}{k+1} \bullet \left[1 - \frac{He}{L2}\right] \qquad \text{with} \quad k = \frac{I2 * L1}{I1 * L2}, \text{ wherein}$$

F = force introduced

He = lever arm of the force F introduced

$I1$ = surface inertial factor of the longitudinal leg (= leg height^3*thickness/12)

$I2$ = surface inertial factor of the vertical leg (= leg width^3*thickness/12)

$L1$ = overall length of the longitudinal leg

$L2$ = overall length of the vertical leg.

The bending moment MA of the vertical legs is minimized for the plate-link chain corresponding to the following formula in given boundary conditions:

$$MA = F * He * \left[1 - \frac{1}{k+1} \bullet \left(1 - \frac{He}{L2}\right) - \right] \qquad \text{with} \quad k = \frac{I2 * L1}{I1 * L2}, \text{ wherein}$$

F = force introduced

He = lever arm of the force introduced F

$I1$ = surface inertial factor of the longitudinal leg (= leg height^3*thickness/12)

$I2$ = surface inertial factor of the vertical leg (= leg width^3*thickness/12)

$L1$ = overall length of the longitudinal leg

$L2$ = overall length of the vertical leg.

Another solution to the object of the invention is reached with a plate for a plate-link chain for use in a variable speed unit of a belt-driven conical pulley transmission, which plate-link chain has plates arranged behind one another in several rows arranged next to another transversely in relation to the direction of motion of the plate-link chain, which overlap transversely in relation to the direction of motion and are connected by means of rocker members penetrating them transversely in relation to the direction of motion, wherein an opening of each plate is penetrated by two rocker member pairs, whose rocker members which face away from each other rest against the front or rear inside of the plate opening and whose rocker members rest against the front or rear inside of plate openings of adjacent plates, wherein the surfaces of the rocker members of each rocker member pair that face each other roll against each other when the plate-link chain bends, wherein the plate is dimensioned such that the bending stress applied to the longitudinal legs extending in the direction of motion or the vertical legs extending perpendicular to the direction of motion of the plate-link chain due to the transmission of force from the rocker members is minimal under given boundary conditions.

In an advantageous embodiment of the plate according to the invention, the bending moment MB of the longitudinal legs is minimal for the plate-link chain corresponding to the following formula in given boundary conditions:

$$MB = \frac{F * He}{k+1} \bullet \left[1 - \frac{He}{L2}\right] \qquad \text{with} \qquad k = \frac{I2 * L1}{I1 * L2}\text{, wherein}$$

F = force introduced

He = lever arm of the force introduced F

*I*1 = surface inertial factor of the longitudinal leg (= leg height^3*thickness/12)

$I2$ = surface inertial factor of the vertical leg (= leg width^3*thickness/12)

$L1$ = overall length of the longitudinal leg

$L2$ = overall length of the vertical leg.

In another embodiment, the bending moment MA of the vertical leg is minimal for the plate-link chain corresponding to the following formula in given boundary conditions:

$$MA = F * He * \left[1 - \frac{1}{k+1} \bullet \left(1 - \frac{He}{L2}\right) - \right] \qquad \text{with} \quad k = \frac{I2 * L1}{I1 * L2}\text{, wherein}$$

F = force introduced

He = lever arm of the force introduced F

$I1$ = surface inertial factor of the longitudinal leg (= leg height^3*thickness/12)

$I2$ = surface inertial factor of the vertical leg (= leg width^3*thickness/12)

$L1$ = overall length of the longitudinal leg

$L2$ = overall length of the vertical leg.

The value for k ranges advantageously from 1 to 3.5.

The invention will be explained below based on diagrammatic drawings for example and with additional details.

There is shown:

Fig. 1 a simple model of a plate in a side view,

Fig. 2 a section of the model from Fig. 1 to explain cutting forces and moments,

Fig. 3 a section from Fig. 1 to explain the course of the bending moments,

Fig. 4 a side view of a half of a conventional and an optimized plate,

Fig. 5 a section of a plate-link chain revolving at a radius R, and

Fig. 6 a side view of a known plate with a rocker member arranged therein.

Fig. 1 is a simplified diagrammatic illustration of the plate 20 of Fig. 6, which is represented by the thick rectangle comprising the longitudinal legs 18 and the vertical legs 20. L1 designates the overall length of a longitudinal leg or of the plate. L2 designates the overall length of a vertical leg 20 or the height of the plate. The arrows F illustrate, as shown in Fig. 6, the active forces. He designates the distance of the active line of the force active adjacently in relation to a longitudinal leg to the longitudinal leg or to the length of the lever arm of the force F referring to the longitudinal legs. J2 designates the surface inertial factor of the longitudinal leg, i.e. $SH^{3*}D/12$, wherein SH is the height of the longitudinal leg (Fig. 4). The surface inertial factor I2 of the vertical leg is $SB^{3*}D/12$, wherein SB is the width of the longitudinal leg (Fig. 4) and D the thickness of the plate.

Fig. 2 illustrates the observed cutting forces and moments, wherein FA represents the force active in the vertical leg and extending in the direction of the vertical leg, MA represents the bending moment of the vertical leg, which is caused by the force F transmitted by the plate and active in the longitudinal direction of the plate-link chain, and MB is the bending moment of the longitudinal leg caused by the force F. F obviously designates the entire force transmitted respectively by a bar, of which each longitudinal leg absorbs half.

Fig. 3 shows the bending moments MA and MB active in a vertical leg 20 and the longitudinal legs 18 as a consequence of the force.

An analysis and calculation in which the bending moment progression is determined initially in sections and then the bending moment overall is determined is shown in the image of Fig. 3. The bending moment in the vertical leg 20 is starting

from its center outward initially constant and directed inward (-), then decreases to zero to be directed outward (+), and is constant along the entire longitudinal leg 18 and directed outward. The amount of the bending moment MB in the longitudinal legs results as follows:

$$MB = \frac{F * He}{k+1} \bullet \left[1 - \frac{He}{L2}\right] \qquad \text{with} \quad k = \frac{I2 * L1}{I1 * L2}, \text{ wherein}$$

The amount of the bending moment MA in the vertical legs results as follows:

$$MA = F * He - MB$$

$$MB = \frac{F * He}{k+1} \bullet \left[1 - \frac{He}{L2}\right]$$

and $k = \frac{I2 * L1}{I1 * L2}$

$$MA = F * He * \left[1 - \frac{1}{k+1} \bullet \left(1 - \frac{He}{L2}\right) - \right]$$

Overall, the following dependencies and influences can be determined:

The bending moment MB in the longitudinal legs is constant across the entire length L1. The influence of the lever arm He on the bending moment MB is nearly linear. When the ratio of the length of the longitudinal leg L1 to the length of the vertical leg L2 increases, the bending moment MB decreases. When the I2/I1 ratio increases, the bending moment MB decreases as well. The firmer the vertical leg is compared to the longitudinal leg, the less bending moment is transmitted into the longitudinal leg. A decrease in the height SH of the longitudinal leg causes a relatively small increase in the maximum stress of the longitudinal leg (stress in its outer region). Additionally, this reduces the portion of bending stress in the maximum stress. In the range from 40% to 70% of the height of the longitudinal leg, the maximum stress

remains nearly constant. The analytical observations furthermore show that the bending stress in the longitudinal leg decreases with increasing length L1 of the plate in relation to the height L2 of the plate.

Analogous dependencies apply for the bending moment MA.

When considering the respective boundary conditions such as available construction, division of the plate-link chain, force to be transmitted etc., the above formulas enable a minimization of the bending stress or the bending moment MB of the longitudinal legs 18 or the bending moment MA of the vertical legs 20, thus allowing the required material and hence the weight to be lowered with a given force F that is to be transmitted. In order to minimize MB or MA based on the above formulas, various mathematical methods can be employed, wherein at least one of the variables is modified and its influence on MB or MA can be examined until MB or MA overall becomes minimal under the given boundary conditions.

Of course only MA or only MB can be minimized, wherein it is advantageous to minimize the two in a mutually adjusted fashion.

Fig. 4 shows the result of an optimization, in which the division T (distance between the rocker surfaces of adjacent rocker member pairs), the length L1, the thickness of the rocker member and the force to be transmitted have been kept constant. DM indicates the effective diameter of a bearing formed by a rocker member pair. The innermost contour line and the outermost contour line show the starting contour of a rocker member. The hatched area shows the contour of an optimized rocker member. As is evident, the height of the longitudinal leg was clearly reduced without influencing the force transmission ability of the rocker member negatively.

The material savings evident from Fig. 4 have the additional advantage that the plate-link chain is suited for higher rotational speeds since centrifugal forces are reduced.

The following table shows examples of advantageous ranges:

Component	Meaningful Tendency for $k_{minimal}$	1.1 Advantageous Range of Values
$I1 = (BH1^3)*T/12$	BH1 as small as possible	2.4 < BH1 < 3.0
$I2 = (BB2^3)*T/12$	BB2 as large as possible	2.7 < BB2 < 3.0
L1	L1 as large as possible	Maximum 20.5 mm
L2	L2 as small as possible	11.6 < L2 < 13

The factor k advantageously lies between 1 and 3.5.

Due to the optimized bending stress of the longitudinal and vertical legs according to the invention, it is possible to accommodate in a small space plate-link chains with increased force and/or torque transmission ability, thus reducing the overall spatial requirement of the variable speed unit. This is achieved above all with an optimized ratio between the dimensions of L1 and L2 and the factors of inertia I1 and I2.

The patent claims submitted with the application are formulation proposals without prejudice for achieving farther-reaching patent protection. The applicant reserves the right to claim additional feature combinations that have so far only be disclosed in the description and/or drawings.

References used in the dependent claims point to the further development of the object of the main claim by features of the respective dependent claim. They

should not be interpreted as a waiver for obtaining independent object-related protection for the feature combinations of the referenced dependent claims.

Since the objects of the dependent claims with respect to the state of the art can form own and independent inventions on the priority date, the applicant reserves the right to make them the object of independent claims or declarations of division. They can furthermore also turn into independent inventions, having a form that is independent from the objects of the preceding dependent claims.

The embodiments should not be interpreted as a limitation of the invention. Rather, within the framework of the present disclosure, numerous changes and modifications are possible, especially such variations, elements and combinations and/or materials that are obvious to those skilled in the art with respect to the solution of the task at hand, for example by combining or modifying individual features and/or elements or procedural steps described in connection with the general description and embodiments as well as contained in the drawings and lead to a novel object or new procedural steps or procedural step sequences through features that can be combined, also to the extent that they relate to manufacturing, testing and operating methods.